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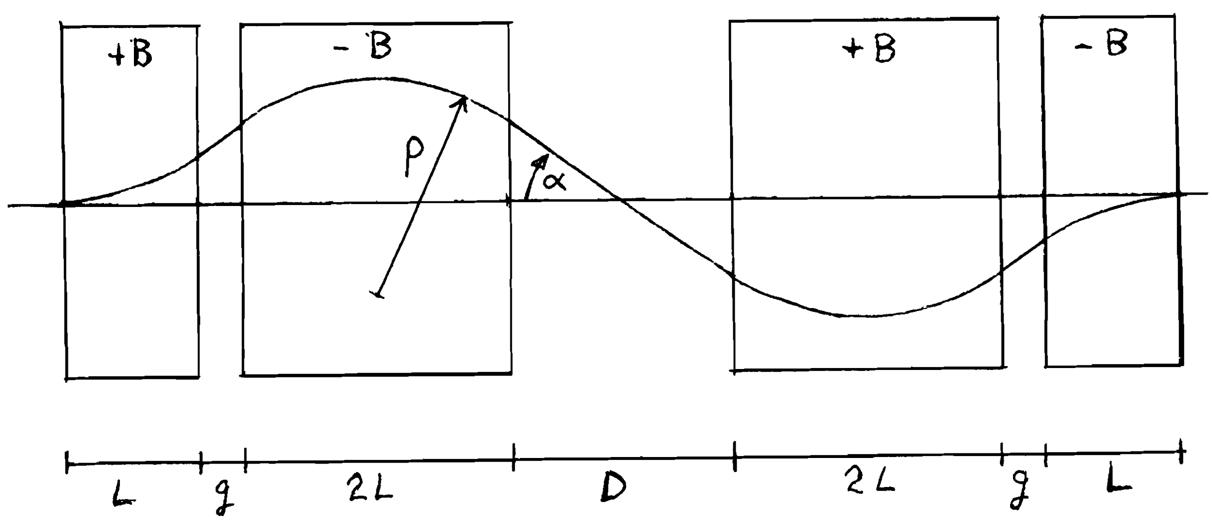
A METHOD FOR PRODUCING LONGITUDINAL BEAM POLARIZATION AT PEP

There are a number of experiments possible at PEP where it is highly desirable to have longitudinally polarized beams. One practical scheme to achieve such beams is discussed here. In this design, the beams will be polarized anti-parallel to one another resulting in an annihilation state of helicity zero. Such a state is of fundamental interest because e^+e^- annihilation is normally assumed to be dominated by the one-photon virtual state which can only have helicity +1 or -1. With the dominant annihilation mechanism suppressed, we have the unique possiblity to study what remains and much more clearly see certain weak interaction effects and possible anomalous electron-hadron interactions, for example.

The basic idea for this polarizer is to use the natural transverse beam polarization expected to be significant at PEP that arises from synchrotron radiation[1] and provide a special set of magnets at one interaction region to transform this transverse polarization to a longitudinal one at the interaction point, then back to transverse again before returning to the normal PEP lattice. The layout of the magnets is shown in the following figure:



The strength of the magnetic field is the same for all magnets; the direction of the field ($\pm\hat{x}$) is indicated for each magnet. In order for the beam to return to its original plane, the drift distance D is restricted to:

$$D = L + 2g$$

Of course field and alignment errors will make it necessary to have some system of correcting magnets available. The product BL (more precisely, $\int B d\ell$) is determined by the desire to rotate the spin by exactly 90° using g-2 precession:

$$\frac{\pi}{2} = \theta_p = \frac{\gamma(g-2)}{2}\,\alpha = \frac{\gamma(g-2)}{2}\,\frac{eBL}{\gamma m}$$

or

$$BL = \frac{\pi m}{(g-2)e} \approx 23.05 \text{ kG-m} \quad .$$

The fact that the field integral is independent of momentum is of great practical importance, and it eliminates many depolarization effects which might arise from the energy spread in the beam. A typical design has B = 8.2 kG and L = 2.8 m.

Synchrotron radiation losses will occur in these bending magents. The fraction f of the total PEP synchrotron power which is radiated in the polarizer is

$$f = \frac{6\alpha}{2\pi}\left(\frac{R}{\rho}\right) \approx 2 \times 10^{-3}\left(\frac{BL}{23 \text{ kG-m}}\right)^2\left(\frac{15 \text{ GeV}}{E}\right)^2\left(\frac{R}{L}\right),$$

where R is the PEP bending radius, and α, ρ, L are defined in the figure. Using the present PEP design and L = 2.8 m, the total power radiated by synchrotron radiation in the polarizer is about 300 kW per beam. Special precautions will have to be taken with the local vacuum chamber to handle this power.

Depolarization effects due to the inclusion of this set of magnets in the PEP lattice originate from three mechanisms: (1) synchrotron radiation in the insertion, (2) non-compensation of the insertion due to field errors and, (3) enhancement of normal stochastic and resonant depolarization due to fringe fields and compensation errors.

The first mechanism appears to be the most important one. It can be pictured as the usual radiative polarization causing the spin to align along (or opposite to) the magnetic field direction. Thus, upon leaving the polarizer, the spin acquires a horizontal component which precesses around the vertical direction in the normal part of the machine and is equivalent to depolarization. A pessimistic estimate of the depolarization rate is to use the Sokolov-Ternov formula[1] modified for the length and bending field of the polarizer. The reason this estimate is pessimistic is because the opposing bends of the polarizer would result in a zero net depolarization if the synchrotron radiation process were continuous. It is the quantum fluctuations that give rise to non-compensated spin motion in the polarizer. To estimate this effect, we note that the mean number of critical energy photons emitted in the polarizer is:

$$\bar{n} \approx 90 \left(\frac{BL}{23 \text{ kG-m}} \right)$$

which is independent of energy. The depolarization rate is proportional to the difference in number of photons emitted in the regions of negative and positive precession. The RMS value of this difference is just $1/\sqrt{\bar{n}}$. Using this argument to modify the pessimistic calculation outlined previously, we obtain:

$$\frac{\tau_{pol}}{\tau_{depol}} \approx 10^{-5} \left(\frac{R}{L} \right)^2 \left(\frac{BL}{23 \text{ kG-m}} \right)^{5/2} \left(\frac{15 \text{ GeV}}{E} \right)^3 .$$

In the example cited above where $L = 2.8$ m and a 90° precession is desired, at 15 GeV per beam the equilibrium polarization is reduced by 7% from its maximum possible value of 92.4%.

In the second depolarization mechanism, non-compensation of spin motion in the polarizer perturbes the precession direction in the rest of the storage ring. If this direction differs significantly from the normal bending field direction (the vertical), then radiative polarization will not build up to the maximum theoretical value. Using the methods of Ref. 2, it can be shown that the change in the precession direction $\delta \hat{n}$ at a given azimuthal position θ in the storage ring due to non-compensation in the polarizer is:

$$\delta\hat{n} = \frac{\delta}{2\sin\pi\nu}\left[\cos\nu(\theta-\pi)\,\hat{x} + \sin\nu(\theta-\pi)\,\hat{z}\right]$$

where ν is the spin precession frequency, $\nu = \gamma(\frac{g-2}{2})$. Thus the angle between the perturbed polarization direction and the direction of the bending magnetic field $\delta\theta$ is $(\delta/\sqrt{2}\,\sin\pi\nu)$. In terms of the net $\int B d\ell$ in the polarizer, $\delta\theta$ is given by:

$$\delta\theta = \frac{1}{\sin\pi\nu}\left(\frac{\int B d\ell_{net}}{20\ \text{kG-m}}\right) .$$

Thus, to insure the stability of the beam polarization, the polarizer must be compensated to within a few gauss-meters and integer spin resonances must be avoided.

The third source of depolarization which is due to betatron motion through fringing fields of the polarizer magnets is expected to be negligible because there are no fringe fields in this system which roll the spin in first order by different amounts depending on the trajectory.

References

1. A. A. Sokolov and I. M. Ternov, Sov. Phys. Doklody 8, 1203 (1964)

2. R. Schwitters, SLAC-PUB-1348, submitted to Nuclear Instruments and Methods.